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Bioeconomic evaluation of an agroforestry system and the potential to recover degraded areas and capitalize producers in the state of Pará, Brazilian Amazon

Avaliação bioeconômica de um sistema agroflorestal e o potencial de recuperação de áreas degradadas e capitalização de produtores no estado do Pará, Amazônia brasileira

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ABSTRACT: The state of Pará has the largest deforested and degraded area in the Amazon, a result from the expansion of extensive livestock, the projects of rural settlement in the Agrarian Reform, mining, timber extraction, hydroelectric power plants and the pressure from large urban centers for food. Reversing the deforestation and soil degradation can thrive with the adoption of appropriate technologies in systems of higher productivity and bioeconomic efficiency, higher social inclusion, and less impact on the environment. The Agroforestry System, formed by the combination of acai, cocoa and black pepper crops, and African mahogany as a forest species, can be one of the alternatives to recover degraded areas and meet the objectives of sustainable development. According to the bioeconomic criteria of viability, this agroforestry system presented a competitive advantage in relation to monocultures of acai, cocoa, and black pepper; due having a higher net present value of US$ 6,508.94/ha; internal rate of return 13.93%; cost-benefit ratio of 1.104; uniform present value of US$ 764.54/ha; occupy more labor and mitigate the emission of greenhouse gases; reduce erosion, recovers water quality and interaction with biodiversity. The inclusion of the opportunity cost of natural assets such as land, water, and forest, and of the benefits with the green certification in the price of products, contributes to the use of good practices in the production, commercialization and preservation of natural resources.

Keywords: bioeconomy; agribusiness; supply chain; productive restoration; Amazon.

RESUMO: O estado do Pará possui a maior área desmatada e degradada da Amazônia, resultado da expansão da pecuária extensiva, dos projetos de assentamento rural na Reforma Agrária, da mineração, da extração de madeira, das hidrelétricas e da pressão dos grandes centros urbanos de alimentos. A reversão do desmatamento e da degradação do solo pode prosperar com a adoção de tecnologias adequadas em sistemas de maior produtividade e eficiência bioeconômica, maior inclusão social e menor impacto ao meio ambiente. O Sistema Agroflorestal, formado pela combinação das culturas de açaí, cacau, pimenta-do-reino e o mogno africano como espécie florestal, pode ser uma das alternativas para recuperar áreas degradadas e atender aos objetivos do desenvolvimento sustentável. De acordo com os critérios bioeconômicos de viabilidade, esse sistema agroflorestal apresentou vantagem competitiva em relação às monoculturas de açaí, cacau e pimenta-do-reino, por ter um valor presente líquido maior de US$ 6.508,94/ha; taxa interna de retorno 13,93%; relação custo-benefício de 1,104; valor presente uniforme de US$ 764,54/ha; ocupar mais mão de obra e mitigar a emissão de gases de efeito estufa; reduzir a erosão, recuperar a qualidade da água e a interação com a biodiversidade. A inclusão do custo de oportunidade de ativos naturais como terra, água e floresta, e dos benefícios com a certificação verde no preço dos produtos contribui para a utilização de boas práticas na produção, comercialização e preservação dos recursos naturais.

Palavras-chave: bioeconomia; agronegócio; cadeia de suprimentos; restauração produtiva; Amazônia.

1. Introduction

In Brazilian Amazon, specifically in the state of Pará, agricultural activities with traditional technology, such as extensive livestock and logging without forest management, have had a major environmental impact due to deforestation and soil degradation in the exploited areas (Santana *et al.*, 2011). The state of Pará, according to the Brazilian Institute of Geography and Statistics – IBGE (2020), has 1,063 mi ha of degraded pasture areas that need to be recovered with high-productivity and low-carbon agricultural systems. Additionally, data from the Rural Environmental Registry (RER) (Cadastro Ambiental Rural – CAR) report that more than 55% of the 281,704 rural properties in Pará have an environmental liability, due to the high percentage of deforested area and soil degradation. It was identified by Santana (2013) that 71.43% of rural properties that received credit from the Northern Constitutional Financing Fund (NCFF) (Fundo Constitucional de Financiamento do Norte – FNO) presented environmental liabilities for having deforestation beyond what is allowed and/or due the soil degradation and water sources.

In this context, the environmental regulation of rural properties requires the RER to be created and a plan presented to correct the existing environmental liability. Otherwise, the producer is unable to access rural credit (Santana, 2013) and is subject to penalties imposed by law.

A path to overcoming such environmental problem can be the productive restoration of degraded pasture areas and the natural assets of rural properties, which account for areas of legal reserve – ALR (Área de Reserva Legal – ARL), areas of permanent preservation – APP (Área de Preservação Permanente – APP), and areas of altered native vegetation and/or in insufficient quantity to meet the forest code – FC (Código Florestal – CF). The ARL and APP are defined in the FC (Lei nº 12.651, de 25/05/2012, Brasil, 2012) as:

> The Areas of Legal Reserve is the area located

> within a rural property or possession, necessary for the sustainable use of natural resources, the conservation and rehabilitation of ecological processes, the conservation of biodiversity and the shelter and protection of native fauna and flora. The Areas of Permanent Preservation (APP) are areas covered or not by native vegetation, with the environmental function of preserving water resources, the landscape, geological stability, biodiversity, the gene flow of fauna and flora, protecting the soil and ensuring the well-being of human populations" (Brasil, 2012, p. 2).

The process of productive restoration to have broad participation by interest groups (producers, government and environmentalists) must meet the economic, social and environmental dimensions. Here, the agroforestry (AFS) – combines agriculture with forest, silvopastoral – combines forest with grassland, and agrossilvipastoril – combines agriculture with forest and grassland, systems can contribute to meeting this socioeconomic and environmental demand through the adequate synergy with the soil, climate, and inclusion of rural communities in the Amazon.

Among the systems, which has the greatest economic, social, and environmental response to offset the environmental liability and improve the quality of life of rural entrepreneurs? Agroforestry systems can be one of the appropriate options, given the greater availability of information and validated technology (Santana, 2020; Oliveira, 2021) particularly from the perspective of including small rural producers, generating income, occupying labor, selling to the brad market, and increasing consumer surplus. However, as there are many different combinations of plants in the AFS's, what is the appropriate combination of crops and forest essences to meet the economic, social, and environmental dimensions?

In the Amazon biome, agroforestry systems show economic, social, and environmental results superior to monoculture crop systems (Sanguino *et al.*, 2007; Varela & Santana, 2009). The AFS proposed here is representative of the diversity of agricultural systems, combining three permanent crops (acai – *Euterpe oleraceae* Mart., cacao – *Theobroma cacao* L., black pepper – *Piper nigrum* L.) and a forest essence (African mahogany – *Khaya grandifoliola*) for use on the property or sale in the market, that is, it contains four inclusive and sustainable value chains (Santana, 2020; Oliveira, 2021). The system is implemented in a rural property in the state of Pará, in the sixth year of the economic cycle.

Black pepper (*Piper nigrum* L) is indigenous to Asia and was implanted in the state of Pará in 1933 by Japanese immigrants. Until 1960s-70s, the pepper cycle ranged 15-20 years, but was reduced to six years due to the lack of a solution to fusariosis disease. As it has a large market demand and production technology dominated by family farmers, pepper provides an economic return, high seasonal occupation of labor and helps to make acai and cocoa feasible, as they take time to enter production and achieve stability of the economic cycle.

Cocoa (*Theobroma cacao*), a crop indigenous to Amazon, has always been grown in AFS in the classic combination of banana, cocoa, and forest (Santana, 2020). It is also a typical product of family farming in the Amazon, has a large market and a strong occupation of local labor (Ribeiro *et al.*, 2004; Maneschy *et al.*, 2010) and economic return due to the good market prices for cocoa beans. In 2015, acai, which was a typical product of floodplain extraction in the Amazon, was classified as a permanent crop by the IBGE (2020), given the expansion of the area cultivated on dry land with irrigation and/or in floodplains areas; which is undergoing rapid expansion in the state of Pará due to the climate and soil conditions, low environmental impact, inclusion of local labor and, mainly, the market prices of the acai fruit that has been continuously evolving in recent years (Santana, 2020).

African mahogany (*Khaya grandifoliola*), in turn, has a wide national and international market and, at the age of 20, can be cut and the wood traded.

This agroforestry system makes it possible to occupy rural labor all year round and generate a flow of production and trade that is also distributed throughout the year, with low impact on the environment; this way contributing to the bioeconomic sustainability of the system (Santana, 2020; Oliveira, 2021).

In 2019, with a production value of US$ 863.58 million and US$ 309.07 million, acai and cocoa, respectively, became the first and second permanent crops of greatest economic importance in the state of Pará (IBGE, 2020). Black pepper, in turn, generates US$ 57.82 million. The harvest period for these crops is distributed throughout the year as follows: acai – July to December; cocoa – November to March; pepper – June to November. The occupation of labor also follows throughout the year, due to the cultural treatment, fertilization and harvesting and processing that complements the demand for local work (Santana, 2020).

The comparative advantage of AFS's bioeconomic efficiency is that production starts in year 1 and extends up to year 20. This makes the business more stable in relation to acai, cocoa and black pepper when grown in monoculture. In social efficiency, there is a large demand for local labor for the activities of harvesting and cultural treatments of the AFS throughout the year. From the stabilization of acai and cocoa crops, which occurs in year 8, 113 dh per ha per year is required, equivalent to 2.1 ha for each permanent job generated (Santana, 2020). In environmental efficiency, the AFS contributes to regularizing the climate, cycling nutrients in the soil, reducing erosion, and interacting with biodiversity. As a result, less use of chemical inputs and mechanization is required (Oliveira, 2021), in addition to making the income flow properly distributed throughout the year, given that cocoa and black pepper allow storage and acai is industrially processed for pulp production (Santana, 2013; Santana, 2020)

This way, with the three inclusive and sustainable agricultural value chains (i.e., acai, cocoa, black pepper) and the mahogany forest chain, the AFS enterprise represents a strong integration of the economic (net income, tax, and fees), social (occupation of local labor, wages and means of survival) and environmental (CO_2 regulation, rainfall, soil erosion control, greater soil fertility, preservation of biodiversity and low use of pesticides) dimensions.

In this context, the objective of this work was to evaluate the bioeconomic efficiency of the AFS (acai, cocoa, black pepper, and mahogany) as an option for the recovery of degraded pasture areas in the state of Pará and the inclusion of small family farmers in the activity. The hypothesis is that this system is socioeconomic and environmentally more profitable, inclusive, and sustainable than the monoculture production of these crops, following the economy of the scope generated with the diversification of crops in the same area, and economy of scale through the social organization of producers.

2. Material and methods

The study area is the municipality of Tomé-Açu, as it concentrates the largest number of producers that use Agroforestry Systems (AFS) of higher economic, social, and environmental consistency in the Amazon (Oliveira *et al.*, 2020; Santana, 2020). The AFS have undergone adaptations over the years, and with the accumulation of knowledge from producers, some systems have been chosen as benchmarks for the economic, social, and environmental support of rural properties. In this environment, the cooperative producers of the Cooperativa Agrícola Mista de Tomé-Açu (CAMTA, Tomé-Açu, Brazil) are taken as representative for the development of this research, due to the experience acquired for more than 50 years.

The production technology was elaborated based on the information obtained from the Executive Committee of the Cacao Plantation Plan (CEPLAC) and from field research with CAMTA producers. The analyzed case refers to a production unit in the municipality of Tomé-Açu, representative of agricultural production in general and the agroforestry systems of the northeast region of the state of Pará. To achieve this productivity, the following was planted: 1,655 feet/ha of black pepper (spacing 2.0m x 3.0 m); 825 feet/ha of cocoa (spacing: 3.0m x 4.0m); 286 feet/ha of acai (spacing: 5.0m x 7.0m); and 35 feet/ha of African mahogany (spacing: 15.0m x 15.0m). The prices of acai, black pepper and cocoa are, respectively, US$ 0.60/kg, US$ 1.60/kg and US$ 2.71/kg (Santana, 2020). The price of standing mahogany tree in the year 20 was estimated to be US$ 1,347.50 (Santana, 2020).

Data on the AFS technology were obtained from the CAMTA producers in Tomé-Açu, whose results continue to be validated and disseminated in other locations in the state of Pará, in the remaining Amazon and outside Brazil (Sanguino *et al.*, 2007; Varella & Santana, 2009; Santana, 2020). The AFS production technology was defined as the average of the systems surveyed at various stages of the production cycle and includes the following: technical operations (preparation of mechanized and manual areas, digging, staking, chemical and organic fertilization, planting and replanting, definitive shading, drip irrigation system and stream water collection, cultural treatments, harvesting and processing), all of which are manual operations; variable inputs (seedlings, paddocks, organic and chemical fertilizers, pesticides, tools, transport); fixed costs (opportunity cost of land, water, and ecosystem services, interest over equity and producer costs, depreciation and maintenance of rural equipment and facilities, technical assistance, taxes and fees).

These data will compose the structure of the unit budget for one hectare of AFS and generate cash flow for the 20-year cycle for acai, cocoa, and mahogany, and for six years for black pepper. In the unit budget, fixed costs and accounting variables make up the explicit cost and the opportunity costs of natural assets, manager service, while equity compensation make up the implicit cost. The sum of these costs generates the economic cost of the AFS. Total revenue is generated by multiplying the price by the quantity of each product harvested over the years.

The opportunity costs of land, water and ecosystem services were estimated as follows: the cost of land is the estimated value of the lease, applying a rate of 8% on the land price, compatible with the average annualized net present value of the rural activities practiced in the region, added by the fertility of the soil and its geographical location in relation to markets and transport logistics (Santana *et al.*, 2014; Azevedo Jr. & Santana, 2022); the cost of water was estimated based on the average price of the provision service and quality of drinking water used in urban and rural supply, and the supply of raw water from rivers and streams used in irrigation and in supplying farms in the northeast region of Pará and Ceará (Barros *et al.*, 2018; Campos *et al.*, 2013); the cost of AFS ecosystem services was estimated using the integrated contingent assessment method, applied to the valuation of natural assets and ecosystem services of Tomé-Açu's AFS's considering the value of provision, regulation, cultural and environmental support services (Santana, 2018; Oliveira *et al.*, 2020).

The effort to incorporate the opportunity costs of these natural assets represent a differential in the analysis of the viability and economic efficiency of rural enterprises, which still consider such assets as free goods. It is also rare to include producer remuneration in benefit-cost analyzes of production systems (Santana, 2020). Not including the implicit costs in the unitary budget of activities underestimates the cash flows and tends to induce a scale of production in which the quantity is greater than that which should be produced from the point of view of socioeconomic and environmental efficiency. This can result in soil erosion, water pollution and deforestation of forests for agricultural production, generating negative environmental externalities for society.

2.1. Indicators of bioeconomic viability

The AFS bioeconomic efficiency was evaluated using the criteria of net present value (NPV), internal rate of return (IRR) and the benefit-cost ratio (BCR). The NPV is (Guittinger, 1995):

$$NPV = \sum_{t=0}^{T} \left(\frac{(TR_t - TC_t)}{(1+r)^t} \right) = \sum_{t=0}^{T} \frac{NR_t}{(1+r)^t} \qquad (01)$$

Where: NPV is the net present value of the AFS; TR is the total revenue of the AFS in year t; TC is the total cost of the AFS in year t; r is the annual interest rate, applied in the temporal update of the values of revenues and costs and which represents the opportunity cost of alternative rural enterprises; NR is AFS's net revenue in year t; T is the enterprise's time, in years.

As a decision criterion, a NPV greater than zero (NPV>0) means that, at the end of T years, updated revenues are greater than updated costs, indicating that the activity is economically viable. A NPV lower than zero (NPV<0), indicates that the activity is not viable, and NPV=0 represents the break-even point (TR=TC) and, therefore, there is no net revenue (NR=0).

Another way of presenting the viability of an enterprise is to transform the NPV into a flow of results with constant value annuity. Thus, the uniform present value (UPV) is the distribution of the NPV values as a uniform annual flow. The UPV is:

$$UPV = NPV \times \left[\frac{r(1+r)^t}{(1+r)^t - 1} \right] \qquad (02)$$

Where: UPV is the uniform present value; NPV is the net present value; r is the interest rate and T is the number of years of the enterprise.

The NPV concentrates the cash flow values into a single amount in year zero and the UPV transforms this amount into a uniform annual series. With this, it is possible to compare enterprises with different cycles. It also offers the manager a view of the returns generated each year. The decision orientation is that only activities with UPV>0 should be continued.

The IRR is the rate that makes NPV=0; that is, it is the indicator that guides the comparison between the return generated by the activity and the rate that reflects the opportunity cost of the money invested in the enterprise. Therefore, an IRR>r shows that the enterprise is viable because it generates a return greater than the opportunity cost, while an IRR<r certifies that the activity is not viable. The IRR is calculated as follows:

$$\sum_{t=0}^{T} \frac{TR_t - TC_t}{(1+IRR)^t} = 0 \qquad (03)$$

Where: IRR is the internal rate of return; T is the period of the enterprise, in years.

CBR is the ratio between the benefit of the activity, or TR, and the TC. A CBR>1 shows that the NR>0 and the activity is economically viable, and the CBR<1 indicates that the enterprise is not viable. The CBR is calculated as follows:

$$CBR = \sum_{t=0}^{T} \frac{TR_t}{(1+r)^t} / \sum_{t=0}^{T} \frac{TC_t}{(1+r)^t} \qquad (04)$$

Where: CBRis the cost-benefit ratio; TR is the total revenue; TC is the total cost; r is the annual interest rate; T is the useful life of the enterprise.

According to Gittinger (1995) and Santana (2020), the prices of products and inputs must be considered at the farm level during the harvest and off-season periods, respectively, given that they reflect value due to the competitive competition of the product and input markets. The prices received by the producers for the sale of the products generate the total revenue and were considered here as the average of the prices practiced during the peak of harvest at the farm level. The prices paid for inputs, which generate the total cost of production, are defined the off-season. The information on costs and revenues related to the agroforestry system's cash flow were monitored over three years on the property. The sale price of the products after incorporating the value of ecosystem services of natural assets and, in turn, with a green or sustainable product certificate, is defined by the inclusion of the sustainability factor ; estimated by the relationship between the opportunity cost of natural assets and the total cost of production. The formula for the sustainability coefficient is (Santana, 2020):

$$\varphi = \frac{OCNA}{TC} \qquad (05)$$

Where: φ is the sustainability coefficient; OCNA is the opportunity cost of natural assets as land, water and forest; and TC is the total production cost.

The sale price of the products is then estimated as follows:

$$P_{qs} = (1+\varphi) \cdot P_q \qquad (06)$$

Where: P_{qs} is the price of the product added to the value of ecosystem services; and P_q is the price of the product at the farm level.

3. Results and discussion

The unit budget with the technical coefficients and the values of the inputs and products make up the AFS cash flow cost and revenue accounts to be used in the benefit-cost analysis (Table 1).

The formation of prices for AFS products is influenced by the performance of intermediaries and large companies, which buy the product and establish local and international price levels according to the quality of the product. Acai and cocoa prices at the producer level are expected to follow the upward trend. The national and international demands for the products are higher than the offers, stimulating the increase of the production.

The price of black pepper, in turn, is found in the "valley" of the 10-year cycle and should start to increase for five or six years. In this case, and for other products, the price during the peak harvest period is considered (Santana, 2020).

The prices of inputs and labor paid by the producer are defined during the off-season for crop, when demand is competitive, and prices reach higher levels (Santana, 2020). Thus, the producer takes local and international prices as signals for his decisions to use good production practices, improve product quality, and not underestimate costs and overestimate revenues. The information regarding prices is obtained from the commercialization agents for companies, cooperatives and intermediaries that operate in the local market.

With prices established by the market, the total revenue is influenced by the demand of companies and intermediaries that fix the price based on the quality and its profit margin, which makes the producer action limited (Santana *et al.*, 2015). In this case, the way out for the producer lies in increasing productivity and quality, in diversifying and differentiating products and in the social organization of AFS entrepreneurs to reduce the cost, increase the scale of production and the bargaining power with agents that operate in the local, national, and international markets (Santana, 2020; Oliveira, 2021).

The offers of acai, cocoa and black pepper are inelastic at price (Santana *et al.*, 2015). Therefore, small changes in quantities can cause large variations in the revenue of these products. In this context, rural wages, given the great dependence on the use of labor, which represents 55.80% of total production costs, should be one of the variables to be monitored (Table 1). An increase of rural wages, pressured by the demand for labor, influences the AFS profitability by raising the cost and producing a drop in supply, since it inevitably reduces productivity and/or causes losses to less efficient producers. On the other hand, cocoa and black pepper can be stored for three to four months, which should be adopted as a strategy to face the price volatility of prices and seasonal costs and minimize their effects on the AFS's net revenue.

The implementation of the AFS, including the planting of crops and trees, was carried out in year zero (Table 1). The production of black pepper starts in year 1 and acai and cocoa in year 3. The production values, costs, and revenues for are the average or each period.

The income from years 1-3 was not sufficient to cover costs, characterizing a negative balance in the AFS that will be compensated as production increases over the economic cycle of crops. Net revenue is positive from year 4, making the total revenue flow generated by the AFS sufficient to cover the updated explicit and implicit costs and ensuring bioeconomic and social viability.

Explicit or accounting costs include variable costs, such as inputs and daily labor, and fixed costs, such as depreciation. The implicit costs include the opportunity costs of the natural assets of land, water, and environmental services, as well as the remuneration of the producer's equity and labor for managing the AFS activity. Traditional analyzes, such as Viana *et al.* (2020), only include the market price of land in the unit budget, and most works do not consider this implicit cost among (Nogueira *et al.*, 2005; Sanguino *et al.*, 2007; Barreto *et al.*, 2012; Oliveira & Tavares, 2016; SUFRAMA, 2016; Almeida *et al.*, 2017).

In the case of AFS's, the traditional benefit--cost analysis was applied, regardless of the term "bioeconomic analysis" in the title of the work. Therefore, when analyzing 17 AFS's with different combinations of crops and forest species in Pará, Silva *et al.* (2018) estimated high values for NPV and IRR ranging between 14.97% and 38.84%. Likewise, Garcia *et al.* (2021) estimated IRR of 10.57% and 24.97%, respectively, for two AFS's in Mato Grosso do Sul and Marques *et al.* (2017) also obtained IRR of 101.45% for an AFS in the northe-ast of Pará. The results supported the contribution of Arco-Verde & Amaro (2014) to create and make available electronic tools for the financial analysis of integrated production systems.

TABLE 1 – Unit budget for the implementation of one ha of AFS (black pepper, cocoa, acai, and African mahogany) irrigated by drip, Tomé-Açu, state of Pará, 2020 (Values in US$ 1.00 of 2019).

Discrimination	Year 0	Years 1-3	Years 4-7	Years 8-19	Year 20
Explicit costs	13,398.74	2,294.23	3,780.00	4,108.88	4,108.88
Implementation of AFS	6 508.52	-	-	-	-
Cultural treatments and harvest	581.35	572.59	1,364.80	1,716.54	1,716.54
Inputs and materials	5,807.91	1,161.84	1,712.42	1,730.46	1,730.46
Technical assistance	25.81	25.81	25.81	25.81	25.81
Accounting	45.33	45.33	45.33	45.33	45.33
Depreciation / maintenance	334.26	334.26	334.26	334.26	334.26
Electric power	68.40	69.30	69.76	69.76	69.76
Taxes and fees	27.16	69.17	205.61	163.44	163.44
Inland transportation	-	15.92	22.02	23.28	23.28
Implicit Costs	2,034.06	2,034.06	2,034.06	2,034.06	2,034.06
Intereston equity	1,289.58	1,289.58	1,289.58	1,289.58	1,289.58
Pro-labore to the producer	134.87	134.87	134.87	134.87	134.87
OC Land (1)	167.78	167.78	167.78	167.78	167.78
OC Water (2)	251.66	251.66	251.66	251.66	251.66
OC Environmental Service (3)	190.17	190.17	190.17	190.17	190.17
Total Cost	15,432.79	4,328.29	5,814.06	6,142.94	6,142.94
Total Revenue	-	2,697.76	12,054.12	8,701.41	20,874.89
Net Revenue	-15,432.79	-1,630.53	6,240.06	2,558.47	14,731.95
Green Net Revenue - GNR	-15,372.30	-1,362.80	7,436.31	3,422.00	16,803.57

SOURCE: Based in (2) Campos *et al.* (2013), (1) Santana *et al.* (2014), (2) Barros *et al.* (2018), ANA (2020), Santana (2020), (3) Santana (2020), Oliveira *et al.* (2020). CEPLAC; CAMTA and field research. The figures for years 1-3 and 4-7 are averages of costs and revenues. Equity is 10% of the investment made in implementing the AFS. In year 20, the revenue of US$ 12,173.48 (US$ 347,8137 x 35 trees) was added, related to mahogany. GNR = $[(1 + \varphi) \times TR - TC]$. In year zero, GNR = ($\varphi$x OC Natural Assets = 60.50/ha). Average exchange rate for 2019: R$/US$ = 3.9451 and OC is the "opportunity cost".

However, by not using the shadow prices of natural assets in the cash flow, these studies tend to underestimate the opportunity cost of production factors and to bias economic viability indicators and influence the process of degradation of natural assets (Georgescu-Roegen, 1975; Farley, 2008; Azevedo Jr. & Santana, 2022). Consequently, these analyses of feasibility overestimate the economic results and add risk to the decision-maker owing to the possibility of defaulting and decapitalizing.

The differential of this bioeconomic analysis is the inclusion of the opportunity cost of natural assets land, water, and forest in the AFS unit budget. The opportunity cost of ecosystem services produced by the AFS was estimated based on the willingness to pay for producers to continue to cultivate the land with agroforestry systems (Santana, 2018; Oliveira *et al.*, 2020). In society's view, this represented 3.11% of economic costs and 7.11% of implicit costs. The opportunity cost of water used for irrigation was 4.15% of the total costs and 9.4% of the implicit costs (Table 1). Soil fertility, location and profitability of the activity explored in the area, according to Santana *et al.* (2014), also contribute to define the opportunity cost of the land (Azevedo Jr. & Santana, 2022), representing 2.74% of the total costs. Taken together, natural assets represent 9.96% of total costs and 22.78% (Table 1) of AFS's implicit costs. These values are generated by natural assets and must be appropriated by producers who use them sustainably.

The total amount of these costs was US$ 609.61/ha, and it can become an irrecoverable environmental liability if they are not remunerated. Therefore, the non-inclusion of these costs in the cash flows, bias the decision making and can trigger the process of degradation of the natural assets by the agricultural and forestry enterprises. This highlights the difference that the analysis of bioeconomic efficiency can make for the systemic competitiveness of rural enterprises.

In traditional analysis, the implicit costs of invested equity and the work of the producer are also left out of the unit budget, which together with the other implicit costs represent 33.11% of the economic cost. This creates a monetary illusion regarding the net cash flow and leads to the expansion of the activity in a non-sustainable way. In turn, the analysis of bioeconomic efficiency can generate a return on investments made in low carbon agriculture, extraction, and livestock systems that is more attractive than those in traditional monoculture crop and extensive livestock activities, as they present high environmental liabilities in all links of their value chains.

To estimate the bioeconomic viability indicators NPV, IRR and CBR (and green indicators GNPV, GIRR and GCBR) generated by the AFS (acai, cocoa, black pepper, and mahogany), the cash flow generated from the last three lines of Table 1 included the economic cost, total revenue, and net revenue, which were updated at an interest rate of 10% per year (Santana, 2020).

When applying the interest rate to update the cash flow, the values of TC, TR and NR become different each year, given that the purchasing power decreases over time; for this reason, the NPV and GNPV were estimated at US$ 6,508.94/ha and US$ 13,411.45, respectively, as values for the year zero of implementation of the AFS. This means that, after 20 years, the system generated an average annual UPV of US$ 764.54/ha and GUPV US$ 1,575.30/ha. These positive values indicate that the activity is viable from a bioeconomic point of view, considering the opportunity cost of the applied resources at 10% per year, and the opportunity cost of the land, water and AFS assets with TR > TC, as long as the conditions of climate, market and prices remain stable.

The IRR of 13.934% and GIRR of 17.648% per year indicate the maximum return on the investment applied in the AFS. These rates make the NPV = 0 and TR = TC. As the IRR was higher than the interest rate of 10% per year, the AFS generated enough revenue to cover the total cost and generate a net return of 3.934% and 7.648% per year. This means that the AFS is bioeconomically viable whether with or without the green products certification.

The BCR of 1.104 and GBCR of 1.215, being greater than 1, showed that the updated TR exceeded the updated TC at a rate of 10% per year. This value means that for each US$1.00 invested in the AFS, at the end of 20 years, a gross return of US$ 1.104, or US$ 0.104 net, is generated for each real invested in the AFS. The result is consistent with the other criteria, as a BCR > 1 indicates that NPV > 0 and IRR > 10% per year. Therefore, by incorporating the added value of ecosystem services generated by natural assets into the product prices, the AFS increases its viability and without degrading the environment.

The comparative results of this AFS with other monoculture production systems are shown in Figure 1. The internal rate of return from activities is around 14% per year. As the interest rate decreases, the enterprises differ. At 10% per year, the AFS's NPV exceeds other activities. Considering the 6.5% NCFF rate for individual entrepreneurs and microenterprises, the AFS NPV is more than double that of the cocoa NPV, which is the second most attractive activity. The NPV of the AFS with green certification is twice the NPV without certification, which is the key element to attracting investment for the recovery of degraded areas with this inclusive and sustainable production system.

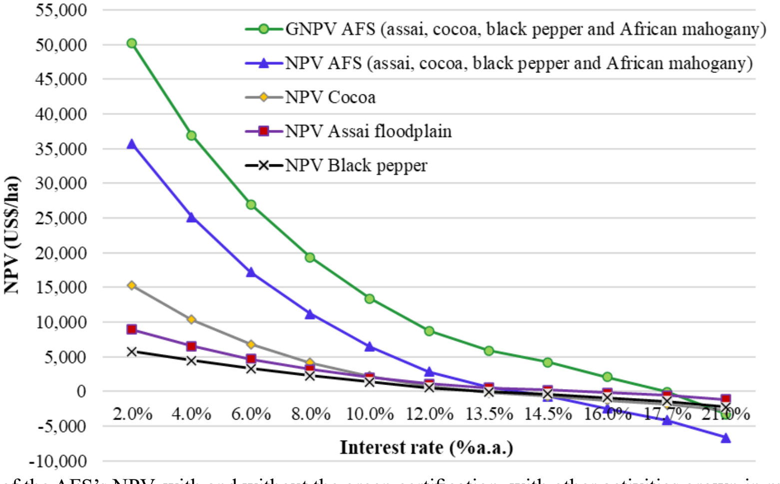

FIGURE 1 – Comparison of the AFS's NPV, with and without the green certification, with other activities grown in monoculture.

SUBTITLE: GNPV – Green Net Present Value.

SOURCE: Field research.

These results show that the AFS performs better due to the savings in scope, since the combination of several activities in the same area contributes to reducing the average cost by rationalizing the use of labor over time, decreasing the use of chemical inputs (i.e., fertilizers and pesticides), controlling erosion, maintaining soil fertility and the flow of ecosystem services that increase productivity (Santana, 2020; Oliveira, 2021). Consequentially, AFS is a more sustainable system than crops grown in monoculture. The difference between the enterprises is that the AFS only gains in scale through the organization of the producers and verticalization of the supply chain, given the need for labor to carry out the harvest and cultural treatments, and the industrial processing to add value to the products and participate in global markets (Santana, 2020).

Regarding the occupation of labor, it was found that every 2.1 ha of AFS generated one job. One job is equivalent to a person working 280 days a year at the AFS, which characterizes the system as having high potential to occupy the local labor force in the activities of cultural treatment and harvesting of products. This result indicates that the AFS is 2.7, 2.0 and 1.4 times more labor-intensive than black pepper, cocoa, and acai from floodplains, respectively, shown in Figure 1 (Santana, 2020).

Currently, the supply of labor in the study area is scarce, a fact that may enable production in collaboration, in which the owner of the AFS offers a portion of the production of acai and cocoa in exchange for other families to manage care of cultural and harvest activities of the production. This practice has a strong impact of social inclusion since each rural property of this AFS can benefit around 130 rural families seasonally. This number of families is enough to start a social organization to verticalize production through the scale and processing of the production (Santana *et al.*, 2007; Santana, 2020).

As for bioeconomic performance, when comparing activities based on the uniform present value of cash flow, we have the following UPVs: US$ 764.54/ha, US$ 307.84/ha, US$ 265.68/ha and US$ 256.05/ha, respectively for the AFS with and without mahogany as forest essence, black pepper, acai and cocoa. Therefore, the AFS generates more than twice the annual value that the pepper and during a period three times longer. The GUPV for AFS with green certification would be US$ 1,575.30.

Studies on the feasibility of these activities in monoculture, or cocoa combined with bananas, show high rates of return, but only because they do not include the implicit costs in the unit budgets. This type of error appears both in technical and scientific works, as well as in institutional programs to support rural entrepreneurs in the Amazon.

The evidence of this technical bias can be found in the studies reported by Viana *et al.* (2020), who found an IRR of 20% per year for irrigated acai, including the cost of land; Oliveira & Tavares (2016), who estimated an IRR of 42.16% per year for irrigated acai on dry land and 58.29% for acai managed in floodplain areas; and Nogueira *et al.* (2005), who estimated an IRR of 44.4% for acai managed in floodplain. For cocoa, SUFRAMA (2003) estimated the IRR of 18.4% per year for in the state of Rondônia, within the scope of the Cocoa Economic Potentialities Project.

In the case of black pepper, Cardoso *et al.* (2018) found an IRR of 46% per year for a four-year cycle. Regarding agroforestry systems, Sanguino *et al.* (2007) obtained an IRR of 36% for an AFS including the opportunity cost of land, Bentes-Gama *et al.* (2005) also obtained IRR ranging between 19% and 86% for three AFS's in Rondônia, Maneschy *et al.* (2010) found an IRR ranging from 12.82% to 15.68% for five silvopastoral systems and Santos *et al.* (2020) studied an AFS in Tomé-Açu, Pará and obtained IRR of 23.4%. The common characteristic of these studies is the non-inclusion of the implicit costs and the lack of concern with the period and location where it was carried out the analysis of the prices paid for the inputs and received for the products in the preparation of the unit budget. These factors, according to Guittinger (1995) and Santana (2020), lead to overestimate revenues and underestimate costs, biasing the result of the economic viability analysis of the projects.

To illustrate the magnitude of this bias, by disregarding the implicit costs, even if keeping prices at the farm level during the peak season for the product and off-season for the input, the results of this work would be reflected as follows: AFS IRR 22.51%, cocoa IRR 21.91%, acai IRR 27.65% and black pepper IRR 27.31%. These increases in rates of return make the activities more attractive and can lead to the creation of many negative effects by the inefficiency in the allocation of credit, land use, combination of chemical inputs, use of labor and good sustainable practices.

The distribution of rain is another factor that affects the production of AFS and, in turn, the stability of the net revenue of producers in the region (Santana *et al.*, 2015). The excess of scarcity of rainfall in the critical stages of the production cycle, such as flowering and fruit formation, can cause a sharp drop in productivity; it becomes further difficult and time-consuming to recover from the damage caused by the climate change, since the reduction in productivity in one year tends to last for two or more years.

This climate risk is not incorporated into the production costs by local managers due to the lack of technical studies, and the ineffectiveness of agricultural insurance to protect against damages caused by climatic changes generated by the ENOS phenomenon; here referring to cases in which the Equatorial Pacific Ocean becomes warmer (El Niño) or colder (La Niña) than the average of the historical period. In the last 20 years, two strong and two moderate droughts have occurred owing to El Niño, and five moderate floods have occurred from La Niña (NWS/CPC, 2020).

The distribution of average rainfall and the seasonal rainfall index, over the period from 1980 to 2019 in Tomé-Açu, is shown in Figure 2 (based on data from ANA, 2020). The average rainfall index is equal to 100 and indicates the regular distribution of rainfall throughout the year. Values above the seasonal index of 100 represent the period of concentration of rain and can indicate harmful impacts to crops when La Niña occurs. In turn, seasonal index values below 100 reveal the dry season and can cause shortage of water to plants when a moderate of strong El Niño occurs.

In the rainy season, March and April concentrate the highest rainfall levels, with index values and rains more than double their respective averages of 100 and 456.1 mm. When this period coincides with La Niña, rainfall can reach levels of 699 mm (case for March 2016) and cause floods, soaking the soil and harming crops. The cocoa harvest occurs during this period, also with a risk to the productivity of the harvest.

Historically (for the last 30 years) the drought period from July to October has an average monthly rainfall in below 60 mm, requiring supplementing water by means of irrigation, especially in dry land crops (Figure 2). The scarcity of rain worsens when El Niño occurs, as the average rainfall in the months of August and September falls below 40 mm and the drought period extends. The crops of acai and black pepper occur in these months, which require irrigation.

To estimate the impact caused by excess or scarcity of rainfall on the net revenue, we consider that the strong incidence of the ENOS phenomenon in the last 30 years would continue throughout the AFS economic cycle. This generates a drop in net revenue of 25% in year 5 and 10% in year 6, given the impacts of rain during the period of flowering and formation of the fruits. The crop failure caused by scarcity and/or excessive rainfall also causes yearly decreases in NPV from US$ 6,508.94/ha to US$ 4,137.55/ha, in IRR from 13.934% to 12.487%, and in CBR from 1.104 to 1.067.

The change in the distribution of rainfall directly influences the AFS and tends to generate a sharp drop in its performance, being even more severe in monocultures. In the given case, the impact would be a 36.46% drop in NPV and 11.40% in IRR. Therefore, considering that this phenomenon has occurred nine times in 20 years, the producers must acquire agricultural insurance to protect themselves from the climatic risk of excess/scarcity of rain, even if they have an irrigation system.

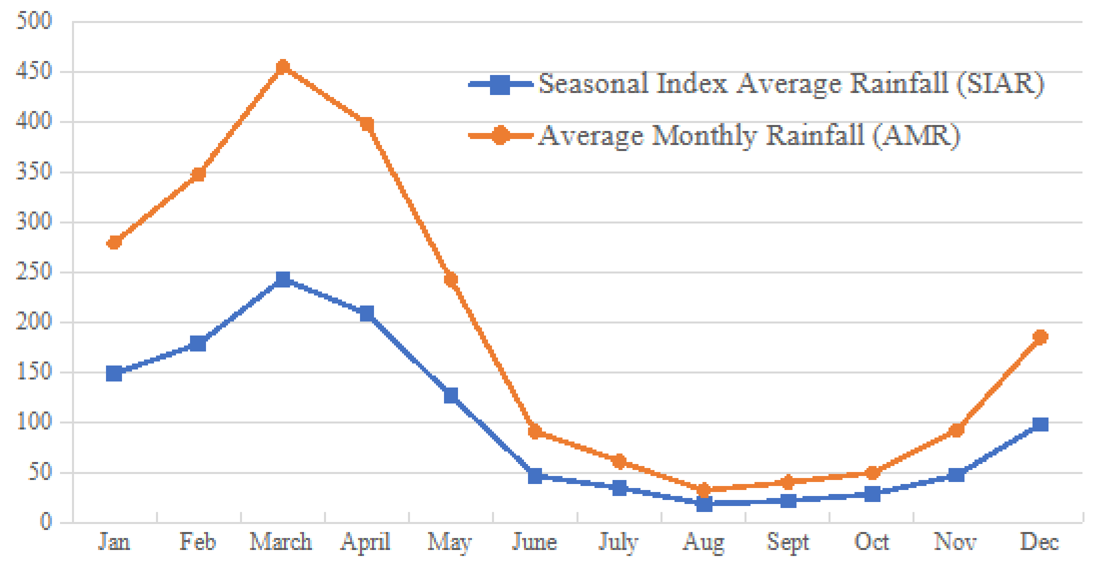

FIGURE 2 – Distribution of the seasonal and monthly average rainfall index in the municipality of Tomé-Açu, 1980/2019.
SOURCE: Based on data from ANA (2020).

4. Conclusion

The products of the three permanent crops included in the presented AFS are inserted in the global food chains and apply the bioeconomy in all processes. In the production, the AFS generates economic return by the net present value, payment of taxes and fees, supply of the market and agroindustries, pro-labor to the producer and greater surplus for consumers in relation to monocultures. In the social dimension, it occupies local labor throughout the year, with a greater percentage of women in the harvest and processing of products, paying salaries and structuring the social organization for access to labor and retirement rights, a strong differential in relation to traditional agriculture and extractivism in the Amazon.

In the environmental dimension, the system has less impact on the soil and the environment than monocultures, as it needs less area for cultivation. Additional benefits include the increase in productivity by reducing erosion, improving rainwater infiltration and soil fertility, reducing use pesticides, and helping regulate the local climate; it also pays for ecosystem services produced by the AFS. All crop residues are incorporated into the soil. In the agribusiness, waste is also treated and reused in the form of bio-input or as energy source, in the case of acai seeds.

The original contribution of this work is the inclusion of implicit costs related to natural assets (land, water, and forest), equity and producer management services. Almost all the technical and scientific works, and institutional programs in support of agribusiness contemplate only the explicit costs. The opportunity cost of natural assets was US$ 609.61/ha (22.78% of the implicit costs), and it can become an irrecoverable environmental liability if they are not remunerated. This causes bias in the allocation of credit, in the size of the area to be cultivated, in the use of inputs and technologies, and impacts in the degradation of soils and forests, and pollution of water and air; in addition to make producers defaulting on their accessed credit. This is one of the causes of deforestation, use of slave labor, low management capacity and low potential for the capitalization of rural entrepreneurs.

The results of this research allow us to conclude that the AFS (acai, cocoa, black pepper and mahogany), with or without green certification of products, can be a potential alternative for investments in the productive restoration of degraded pasture areas, areas degraded by mineral exploration (Silva *et al.*, 2020; Salomão & Santana, 2021) and rural settlement areas; as well as enrichment of the areas of forest reserves occupied by quilombolas, indigenous and rural settlement communities in the Amazon. With economic, social, and environmental results proving superior to monocultures, AFS can be a sustainable alternative for the capitalization of entrepreneurs and local development in the Amazon, since the products are already inserted in the global food chains.

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